



Highlights from the CMS Experiment

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Outline



- LS2 Status and Phase 2 Upgrade
- Highlights from Physics results
 - ✓ Standard Model
 - Higgs Physics
 - ✓ Searches for New Physics

... 12 CMS talks at the Conference

Standard Model and Higgs

- H. Liao, Top quark physics at CMS
- A. Lanev, Electroweak measurements at CMS
- O. Kodolova, Results on QCD physics at CMS
- A. Tulupov, B physics results from CMS
- G. Mitselmakher, H(125) measurements at CMS

BSM

- A. Kaur, Exotic physics signatures at CMS
 M. Savina, Dark Matter searches at CMS
 G. Kole, Searches for additional Higgs bosons at CMS
 E. Lipka, Towards new physics through precision
- J. Babbar, Search for New Resonance in Photon and Jet final State using CMS Data

Heavy lons

- S. Petrushanko, Heavy-ion physics at CMS
 - Highlights from the CMS Experiment



<u>http://cern.ch/cms-results/public-</u> <u>results/publications-vs-time/</u> 20.08.2021



LS2 Activities





20.08.2021



CMS Phase 2 Upgrade







LHC Timeline and Data Taking







CMS Dataset Run-2

- 2016-2018: 137 fb⁻¹ of pp data "good for physics"
- data-taking efficiency > 92% (2018: 94%)
- number of pp interactions per beam crossing (PU): $\langle \mu \rangle$ = 34



- ✓ ~160 fb⁻¹ of proton-proton collisions at 13 TeV delivered during Run 2
- Also collected and analyzed Heavy Ion pPb and PbPb collisions (see dedicated report by S. Petrushanko)



CMS "full Run 2" Performance



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Comparison of Z mass resolution Before and after final calibration Included in Legacy Run 2 rereco

Performance of the CMS muon trigger system in proton-proton collisions 13 TeV

JINST 16 (2021) P05014



b-jet performance using **Deep Neural Networks**

CMS-DP-2021-004

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JINST 16 (2021) P07001





Summary of Standard Model Tests



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High rate at the LHC

- Provides statistic to study inclusive and differential distributions
- Good understanding of the detectors allow for precision measurements
- Test p-QCD and PDF in different regimes, deviations may indicate presence of new physics, EFT interpretations (see talk by E. Lipka)
- Developments and testing of new MC generators and techniques \checkmark **CMS** Preliminary September 2020



W and Z production

36 pb⁻¹ (7 TeV)

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iminary, 43 pb⁻¹ (13 TeV 1 (8 TeV)

pp

[dd]

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 $\times 10^4$

 10^{3}



Gauge Boson Differential x-sections



Measurements of different production processes continue and more and more differential ones \Rightarrow differential cross sections of the transverse momentum p_T, the angular variable ϕ^* , and rapidity of lepton pairs - tests in (x,Q²) space



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NLO pQCD Strinjent Tests: V+jets, VV+jets







(qd)

EWK Self-Couplings: Multi-bosons



✓ WWZ – 3.4 (4.1) σ

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http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/AQGC.html



QCD: jet physics







Dijet Azimuthal Correlation (N_{jets} > 2,3,4)





The leading order (LO) PYTHIA 8 dijet event generator exhibits small deviations from the measurements but shows significant deviations at low-pT

The HERWIG++ event generator exhibits the largest deviations of any of the generators The tree-level multijet event generator MADGRAPH in combination with PYTHIA 8 for showering, hadronization, and multiparton interactions provides a good overall description of the measurements



Mass of "top": Legacy of Run 1/2





see talk by H. Liao for details



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Running of the Top Quark Mass/Vtb

 $|f_{IV} \cdot V_{tb}| = 1$

Beyond leading order in perturbation theory the strong coupling constant and the quark masses are subject to renormalization



The no-running hypothesis is excluded at above 95% confidence level

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Non-direct Vtb measurements ✓ from B-hadron and t-quark decays (CKM unitarity, generation number=3)

 $R = \mathcal{B}(t \to Wb) / \mathcal{B}(t \to Wq) = |V_{tb}|^2 / (\sum_q |V_{tq}|^2) = |V_{tb}|^2$

✓ |V_{tb}| > 0.78 (CDF), 0.99 > |V_tb| > 0.9 (D0)

Direct Vtb measurements from single t-quark production in t-, Wt, s-каналах ($\sigma \sim {V_{tb}}^2)$







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 $B(B_s^0 \to \mu^+ \mu^-) (10^{-9})$ с



Higgs Mass Measurements





Run-2/2016 combination

 $m_{\rm H} = 125.46 \pm 0.16 \,({\rm total})\,{\rm GeV}$

The Higgs boson mass measurement uncertainty is still dominated by statistics

from talk by G. Hamel de Monchenault (HEP2021)





• currently the most precise measurement (1.1‰)

• central value consistently used in CMS analyses

see talk by G. Mitselmakher for details

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CMS-HIG-19-004

PLB 805 (2020) 135425



Higgs Properties (selected)



(fb) Simplified Template Cross Sections (SXTS) $H \rightarrow \gamma\gamma, \tau\tau, ZZ^*(\rightarrow 4I)$ produced via gg, VBF, VH, and t(t)H

10²

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Ratio to SM

CMS-PAS-HIG-19-010





The rate for Higgs bosons production in association with either one (tH) or two (ttH) top guarks in multi-lepton channel



Contraints on ttH anomalous CP coupling, combining $H \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$

CMS-HIG-19-009, sub. to PRD







Evidence for $H \rightarrow \mu\mu$



First evidence of the coupling of the Higgs boson with fermions of the second generation



$H \rightarrow \mu\mu$ candidate in gluon fusion channel, $m_{H} = 125.46 \pm 1.13$ GeV



targets ggH, VBF , VH, ttH

Drell-Yan background considerably reduced by VBF topology requirement (two forward jets)





Higgs Differential Cross Sections



Differential cross sections as a function of the transverse momentum and rapidity of the Higgs boson, the number of associated jets, and the transverse momentum of the leading associated





Search for pair-production of Higgs



- Shape of Higgs potential depends on Higgs self-coupling (SM: λ_{HHH} = λ_{HHHH}) → can be accessed directly from Higgs pair and via higher order electroweak corrections of single Higgs productions
- Inclusive production via vector boson fusion provides direct access to HHVV coupling (C_{2V})



Constraints on coupling modifiers (wrt SM predictions) $\kappa_{\lambda} \& \kappa_{2V}$ from HH \rightarrow 4b final state at 95% CL -2.3 < κ_{λ} < 9.4 and -0.1 < κ_{2V} < 2.2

Observed limit on cross section @ 95%CL: 3.6 x SM

from talk by K. Mazumdar (QCD 2021)



Searches for Extra Higgs/Exotic Higgs Decays



 $X \rightarrow aa \rightarrow 4b$ CMS-PAS-B2G-20-003



The analysis is restricted to the mass ranges m_a from 25 to 100 GeV and m_{χ} from 1 to 3 TeV.

see review talk by G. Kole

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 $H \rightarrow Invisible$

A broad program in BSM Higgs searches:additional Higgses, invisible decays, lepton-flavourviolating decay and 2HDM+scalar models with h \rightarrow aa, Charged Higgses,... EPJ C 81 (2021) 13



Observed upper limit from Z (ℓℓ) H, H→invisible: BR(H→invisible) < 29% @95% CL 20.08.2021



Single and double charged

Higgs boson

No significant excess beyond standard model predictions is found. Charged Higgs boson mass explored: 200 – 3000 GeV

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Higgs decays and long-lived particles



Search for Long-Lived Particles produced in pairs

- ✓ with a mean decay length between 0.1 and 100 mm (i.e. within the beam pipe)
- ✓ each decaying into two or more quarks







Example of Dark Matter Searches



Effective approaches to DM

- Simplified DM model (SMDM) with jne DM spin ½ particle χ, one mediator
- Flavour-violating vector mediator, color charged scalar mediator
- Extend higgs sector (higgs portal) and/or gauge sector (2HDM+a/S/Z')
- Double portals (scalar and vector mediators)
 etc

m_{Med}-m_{DM} plane for di-jet and di-lepton searches (SMDM)



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Z'



see review talk of M. Savina

Exclusion limits for the pseudo-scalar model as a function of M_{med} for different MET based DM searches from CMS





Summary of Exotica Searches



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV see review talk by A. Kaur



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Example of Supersymmetry Searches



CMS has a rich SUSY search program setting strong limits on many models

• analyses optimised to tackle difficult corners of the phase space (stop corridor, compressed scenarios)



from talk by G. Hamel de Monchenault (HEP2021)



Summary



Despite the pandemic, the CMS Physics Analysis, LS2 and Phase 2 Upgrade activities are progressing well

- Many new analyses made public for Summer Conferences, \checkmark http://cms-results.web.cern.ch/cms-results/public-results/preliminaryresults/CMS/index.html
- Physics Briefings at: <u>https://cms.cern/tags/physics-briefing</u>
- Run 3 preparation ongoing \checkmark
 - LS2 work mostly complete
 - Detector almost ready to be closed to cool down and commission the magnet by October
 - Currently taking cosmic data for alignment
- Phase-II Upgrades
- Excellent progress in all projects \checkmark
- \checkmark All Technical Design Reports prepared
- More physics projections for HL-LHC starting to appear

we are looking forward to

SM

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CRUZET Cosmic RUn at ZEro Tesla for detector alignment July/August 2021

